

A PRELIMINARY STUDY OF THE INFLUENCE OF
CHLORIDES UPON THE GROWTH OF
CERTAIN AGRICULTURAL PLANTS

BY

W. E. TOTTINGHAM

DISSERTATION SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF
THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY WITH THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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A PRELIMINARY STUDY OF THE INFLUENCE OF CHLORIDES ON THE GROWTH OF CERTAIN AGRICULTURAL PLANTS.¹

W. E. TOTTINGHAM.

INTRODUCTION.

Investigations on the nutrition of higher plants early led to the conclusion that carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, potassium, calcium, magnesium, and iron are essential to their growth. Less certainty has attended our knowledge of the rôle of sodium, silicon, and chlorine in plant growth. Various observations, however, seem to have led to general belief that, altho exerting beneficial effects under certain conditions, these elements are unessential for most plants. As none of the seed plants tested have been deprived of chlorine thru successive generations, it appears that the necessity of this element has never been adequately investigated. Apart from this relation, however, it is certain that some seed plants contain much more chlorine than others, that some can endure much higher chloride concentration about their roots than is possible for others, and that differences in the amount of this element in the soil are frequently accompanied by characteristic differences in growth and development. In view of these considerations it appears to be

¹ Botanical contribution from the Johns Hopkins University, No. 54. This work was done partly in the Department of Agricultural Chemistry of the Wisconsin Agricultural Experiment Station and partly in the Laboratory of Plant Physiology of the Johns Hopkins University. The writer is indebted to Professors E. B. Hart and B. E. Livingston, of these respective institutions, for facilities and advice extended to him in the course of these investigations. Professor Livingston has also aided greatly in the preparation of this paper.

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important to investigate rather fully the effects of chlorides in nutrient media and to reconsider their relative importance in fertilizer practice.

The literature of this subject presents considerable evidence that beneficial effects upon plant growth may be expected to follow the application of chlorine to the soil in the form of sodium chloride, or common salt. For example, Griffiths (21, p. 250-256)² refers to the use of salt as a fertilizer from ancient times, and states that about 250,000 tons of the substance are used annually in the United Kingdom for agricultural purposes. Hall (22, p. 334, 357) mentions the English practice of top dressing mangolds, potatoes, and barley with salt. In the last instance, this was done for the purpose of stiffening the straw. He ascribes the benefits of this practice to liberation of potassium from feldspars. Cameron (12, p. 108) says: "In spite of the fact that it does not contain a conventional plant food, sodium chloride appears to produce results quite similar to those produced by the usual fertilizer salts. Its use has been followed generally by an increased yield of crop, but occasionally by a decreased one, and it appears not improbable that further investigation would show sodium chloride to have a considerable value as a fertilizer." Other authorities express different opinions. Thus, Hilgard (29, p. 76) regards the usefulness of common salt in fertilizers as entirely subordinate, and Wheeler (75, p. 246-249, 334, 357) treats chlorine as unessential for plants. These writers consider 0.10 to 0.25 percent of NaCl in the soil as sufficient to inhibit the growth of cultivated plants, the effect depending upon the dryness of the soil.

The available evidence regarding the effects of chlorides upon plant growth would seem to justify further investigation. For several years the writer has been interested in this problem, and the present paper is a report of the results already obtained.

I. REVIEW OF PREVIOUS EXPERIMENTATION.

IS CHLORINE ESSENTIAL?

Early in the development of the water-culture method in the study of plant nutrition certain investigators obtained results which led them to consider chlorine essential for the complete development of the buckwheat plant. The chief investigation in this field is that of Nobbe and Siegert (48), who observed peculiar physiological disturbances in buckwheat plants grown in chlorine-free nutrient solutions. The apparent need for chlorine first became noticeable at the fruiting stage, when it appeared that KCl and CaCl_2 were superior to NaCl and MgCl_2 as sources of this element. Certain phenomena of

² References are to "Literature cited," p. 28.

growth observed in these experiments led to the conclusion that chlorine functions in the translocation of carbohydrates. Wagner (74) and Aschoff (2), employing somewhat different nutrient solutions and methods of culture, arrived at directly opposed conclusions regarding the necessity of chlorine for the growth of maize; and in the hands of Beyer (4), peas produced seed, but oats failed to do so, when grown in a chlorine-free nutrient solution. The results of these early investigations were decidedly conflicting and they can scarcely be expected to have approached finality, having been conducted when the problem of the physiological balancing of salts in nutrient solutions was as yet hardly appreciated.

In the Laboratory of Plant Physiology of the Johns Hopkins University³ buckwheat has been reared repeatedly to the production of apparently perfect seeds, employing as a nutrient medium the three-salt solution of Shive (57). These results are in agreement with those of Shulov (59), who found chlorine unessential for buckwheat. Furthermore, from the results of extensive series of water and sand cultures, Prianishnikov (52) concludes that "the generally accepted opinion of the usefulness of chlorine as such for plant life is not corroborated."

From the preceding brief review it appears that chlorine, aside from the small content of the seed, is unessential for the complete development of buckwheat, and probably also for others of the common seed plants.

STIMULATING EFFECTS OF CHLORIDES.

As regards the germinating stage of growth, it should be noted that Jarius (33) observed stimulation of several species of seeds by soaking in 0.4 percent solution of NaCl, while other salts tested were not so effective. Plate (51) has reported that the stimulating effects of certain chlorides upon the root and sprout growth of oats during germination were markedly different from those of the corresponding nitrates. The effectiveness of the chlorides in decreasing order is given as follows: NaCl, KCl, RbCl, LiCl, CsCl.

As regards the complete cycle of growth, early English experiments with the small grains (23) gave results favorable to the use of common salt as a fertilizer. Increases of 1.4 to 11.4 bushels of grain per imperial acre followed the application of salt at rates of 300 pounds or more, and in some cases the weight of grain per bushel and yield of straw were increased also. On the other hand, results obtained by

³ Incident to investigations of Earl S. Johnston. The Johns Hopkins University Circular, March, 1917, p. 211-217.

Sir John Lawes (39) led him to oppose this practice. To one of two plots which had been continuously cropped with wheat since 1843 he added salt at the rate of 300 pounds per acre per year, from 1851 to 1853, in addition to the common dressing of mixed minerals and ammonium salts added to the two plots. There was no appreciable variation in the yields from the two plots, either during this period or in the succeeding ten years. In cooperative field tests of common salt at the rate of 300 pounds per acre Voelcker (72) obtained an increased yield of barley in one region but a decreased yield in another. Tests conducted by Shelton (55) in the United States led to unfavorable deductions, despite gains in yield. In one of these tests an application of 300 pounds of salt increased the yield of wheat 4 bushels per acre and produced a persistent brightness of the straw. Brooks and Thomson (8) applied 250 and 400 pounds of chloride of potassium in comparison with equal amounts of the sulfate, as constituents of a complete fertilizer, and found the two equally effective with grains and grasses, but clover was injured by the chloride.

It seems to have been a rather general practice in Great Britain to top-dress grassland with common salt. Investigations conducted by the Royal Agricultural Society (13) led, however, to adverse recommendation regarding such practice. Applications of 500 pounds of salt per acre to soils which were mostly clays, in various parts of England, produced no appreciable effect upon either the quantity or quality of grass produced. It may be noted, however, that Voelcker (70) had previously obtained increased yields from the use of salt in similar tests. In this country Jones (35, p. 71) observed nearly 100 percent increase in weight of meadow fescue (*Festuca ovina*) on land which had received salt at rates of 200, 300, 500, and 1,000 pounds per acre to kill hawkweed (*Hieracium aurantiacum*).

The mangold and the sugar beet, closely related genetically and supposed to have originally inhabited the salty sands of the seashore, are generally stimulated to greatly increased production by sodium chloride. Thus, Voelcker (68), altho he had previously failed to obtain an increase of the crop on a stiff, calcareous clay, applied common salt to mangolds on a light sandy soil at rates of 100, 300, 500, and 700 pounds per acre, and obtained increased yields from the two medium applications. The maximum increase over the yield from untreated plots amounted to over 50 percent and was obtained from the 500-pound application. This investigator believed that the salt functioned by retarding the development of the plant. More recently Voelcker (73) obtained, from applications of salt up to 600 pounds per acre on a sandy soil, supplementary to farm manure and min-

eral fertilizers, much greater yields of mangolds than were obtained where the salt was omitted. Since NaNO_3 was included among the mineral fertilizers applied, Voelcker attributed the effects of the NaCl specifically to its chlorine content. Lawes (39) had earlier obtained progressively smaller yields of mangold as he increased the application of salt from 500 to 1,000 pounds per acre and concluded that its use was unjustified, but his applications seem to have been excessive.

Among American investigations, Lyon and Wiancko (46) found the use of 600 pounds of common salt per acre upon a deep, medium loam without effect on either the yield or the percentage of sugar of the sugar beet. Brooks and Thomson (6), employing the salts at rates of 250 and 400 pounds per acre, obtained a slightly higher yield but a diminished percentage of sugar from KCl as compared with K_2SO_4 in one season, but found the two salts equally effective in another season.

As to other crops, the yield of turnip has responded variably to the application of common salt in English trials (69). The same is true of the use of KCl in American experiments. Thus, at the New Jersey station (81), 160 pounds per acre of KCl in mixed fertilizers was less productive than an equal quantity of K_2SO_4 , while at the Massachusetts station (9) 250 pounds of KCl produced a greater yield of crop than did an equal quantity of K_2SO_4 , the salts being employed in a complete fertilizer ration.

The cabbage seems to respond decidedly to the application of chlorides under certain conditions. Thus, Dyer (17), operating upon a light clay soil in a season when drouth occurred at the critical growth period of the plant, obtained practically a doubled yield by applying 300 pounds per acre of NaCl , in addition to the usual ration of manure, sodium nitrate, and phosphates. Contradictory results were obtained by Brooks and his coworkers (7), who found KCl to give greater yields than K_2SO_4 in some cases, but smaller yields in others, with a tendency for the former salt to produce soft cabbage heads. As a result of their tests upon medium clay loam, the latter investigators state that "clearly, climatic conditions have an important influence in determining the manurial effects of these salts," and "in hot dry seasons the differences between the chloride and sulfate are small on the cabbage."

At the Massachusetts station KCl has been compared with K_2SO_4 as a source of potassium upon a variety of field and truck crops. In the results of three years, summarized in 1904 (10), the chloride was superior with late crops while the sulfate proved best for early crops. The investigators remark that "In soils of fair retentiveness of water

only beets were decidedly best on KCl" and "Chlorides increase the wateriness and tend to delay the maturing of crops." In applications of 250 pounds of potassium salts with bone meal (11), berries and garden plants did equally well on the two salts, while the soybean yielded poorly from the chloride.

Tests conducted by Gonehalli (19) upon mango trees in the Province of Bombay, British India, gave striking results. Addition of common salt to the soil about the roots at the rate of 10 pounds per tree gave an increase of nearly 150 percent in the number of fruits produced the following year, as compared with the yield from untreated trees. The same writer reports marked increases in the yields of coconuts and rice from applications of salt.

Probably the common potato has received more attention than any other crop relative to its response to the application of chlorides, especially in comparisons of KCl with K_2SO_4 as a source of potassium. As regards the numerous experiments on this question in the United States, the published descriptions of the tests are often so meager as to make conclusions uncertain. This is especially true of those cases in which the method of determining starch is not given, for, as will appear in part 2 of this paper, the use of specific gravity values for this purpose is unreliable.

In an early trial of common salt upon various English farms (71) at the rate of 400 pounds per acre, both alone and as part of a complete fertilizer ration, the treatment either resulted in toxicity to the potato or produced no effect. Equal yields of tubers having the same percentage of starch were obtained by Pfeiffer and others (49) from the use of KCl and K_2SO_4 . About 200 pounds of each salt per acre were applied, in a complete fertilizer with lime, to two varieties of potato in confined portions of an unproductive sandy soil. The use of $MgCl_2$, however, in conjunction with K_2SO_4 , seriously depressed the yield of tubers and somewhat decreased their starch content. Favorable effects upon yield from the use of 600 pounds of KCl per acre led Emery (18) to the extreme statement that " K_2SO_4 is not desirable for the potato when KCl is obtainable."

Investigations of these two salts with two varieties of potato and two types of soil in New Jersey (80) resulted in a greater yield with KCl, altho the tubers were more watery and of poorer quality than those produced with K_2SO_4 . Jenkins (34) applied 63 to 240 pounds per acre of either KCl or K_2SO_4 in a complete fertilizer ration on different farms. Neither salt was decidedly superior as to yield of tubers, but the crop which received KCl contained 0.5 percent more water than that produced by K_2SO_4 . In a dry season Taft (63) ob-

tained slightly lower yields from KCl than from K_2SO_4 , each salt having been applied at the rate of 320 pounds per acre in a complete fertilizer ration. Potassium salts at the rate of 400 pounds per acre were applied with acid phosphate and sodium nitrate to two varieties of potato and two types of soil in Vermont (31). Without sodium nitrate the chloride of potassium produced tubers richer in water and poorer in starch, as compared with those produced by the sulfate. This difference disappeared with the complete fertilizer ration.

Davidson (15) added 100, 200, and 300 pounds of potassium salts per acre in a complete fertilizer applied to three varieties of potato, in Virginia. As an average of all the plots which received each salt the tubers produced by KCl were reported to contain 0.7 percent less dry matter, but 0.6 percent more starch in the dry matter, than those produced by K_2SO_4 . Brooks and his coworkers (79) have devoted special attention to the potato in tests of the relative values of muriate and sulfate of potash. The Beauty of Hebron variety of potato seems to have been chiefly employed by Brooks, who extended his investigations to several regions and soil types. Potassium salts were applied at rates of 160 to 263 pounds per acre in a complete fertilizer. Samples of the tubers were tested for cooking qualities by various families. In a majority of cases the results from K_2SO_4 were superior to those from KCl as to yield, composition, and quality. The tubers produced by the former salt were drier and superior in whiteness, mealiness, and flavor, as compared with those produced by the chloride.

TOXIC EFFECTS OF CHLORIDES.

Loew (45) ascribes to sodium chloride, in sufficient concentration, a depression of photosynthetic formation of carbohydrates by leaves and a decrease in the percentages of sugar in the sugar beet and of starch in the potato. Harter's comparison (26) of his own results with those of other investigators, relative to the growth of seedlings in salt solutions, indicates that lupine and maize are injured at lower concentrations of NaCl than is wheat. In Harter's investigations this salt was not toxic to wheat below a concentration of about 300 parts per million in the solution.

Takeuchi and Ito (64) found calcium and magnesium chlorides injurious to the rice plant when 0.1 percent of each was applied to a rich loam in pot cultures, but 0.05 percent was not particularly injurious.

Applying various sodium salts to a sandy soil in pot culture, supplementary to a complete fertilizer containing K_2CO_3 , Suchting (62) observed a depression in the yield of potato tubers and also in the

percentage of starch in these organs from the use of NaCl. The application of NaCl amounted to 580 pounds per acre foot (4,000,000 pounds) of soil. Altho it was found that chlorine migrated into the tubers, there was no apparent correlation between such migration and the extent of injury observed.

At the Rhode Island station (76), the chlorides of calcium, magnesium, and ammonium were added to completely fertilized soil in large pots. With a soil of acid reaction, calcium and ammonium chlorides were decidedly toxic to cereal grains and to the potato, but magnesium chloride was not injurious in the concentration tested. The toxicity of the former salts was overcome by liming. It was concluded from these results that all of the apparently conflicting evidence regarding poisonous actions of chlorides upon plants, when these salts are applied in moderate quantities, might be harmonized upon the basis of differences in the chemical reaction of the soil.

In extensive investigations on the effects of chlorides in alkali soils, Harris (25) has found sodium chloride, at 0.2 percent concentration in the soil, to reduce the germination of wheat by half. He finds this to be the most toxic of the several common chlorides investigated. Harris found the toxic effect of chlorides to be only half as great in sand as in loam, the effect in dry soil being less than in wet. The limit to productiveness of the soil is set by this investigator at 0.3 percent of chlorides in loam and 0.2 percent in coarse sand.

SPECIAL PHYSIOLOGICAL RESPONSES TO CHLORIDES.

The responses of plants to the presence of chlorides in the nutrient medium may be divided into two apparently distinct classes, namely, those which affect the form of the plant (morphological) and those which influence its composition (compositional).

Marked changes in structure and transpiring power of plants under the influence of sodium chloride have been observed by Harter (27) with wheat. Employing a saline soil in which NaCl formed about 70 percent of the total salts, he diluted this with garden loam, so as to obtain soils containing 1.4, 1.0 and 0.7 percent of NaCl, on the basis of dry weight. Tumbler cultures of these soils were sealed with paraffin to permit comparative transpirational measurements by weighing. In general, the epidermal cells of the plants in the saline soils were smaller than those of the control plants grown in the loam soil, and the cuticle was thicker in the former case, the leaf surface developing a conspicuous amount of bloom. Leaves from cultures so modified lost but one-third to half as much water, relative to dry weight, as did leaves from the control culture. On the other hand,

leaves from cultures in which the saline content of the soil was insufficient to affect the amount of bloom on the leaves showed 10 to 20 percent higher transpiration rate per unit of leaf area than similar leaves from the control plants.

As to the exterior form of the plant, Hansteen (24, p. 318) observed, with water cultures, that solutions containing chlorides, as compared with other salts, produced wheat plants with longer roots and shorter leaves. He considered this condition to be a response to a decrease in the rate of water absorption, both brought about by an increased absorption of the chlorine ion.

The chemical composition of the plant, as this may be influenced by the addition of chlorides to the soil, seems to have been investigated but little, save in the case of the sugar beet and potato. Some of these effects have been pointed out already (Brooks and Thomson, 6, 10; Pfeiffer *et al.*, 49; Hills, White, and Jones, 31; Davidson, 15; Brooks, 79; Suchting, 62). According to Bolin (5) NaCl and KCl applied with the usual fertilizers in Sweden, while increasing the total crop, appeared to increase the wateriness of the sugar beet and potato. De Ruijter de Wildt and his coworkers (16) found an application of 267 pounds of common salt per acre without effect upon the percentage of sugar in the sugar beet, but an excessive salt content of the soil (due to flooding with sea water) depressed the sugar content. They also note some disturbances in the distribution of nitrogen compounds.

2. EXPERIMENTATION.

GENERAL CONSIDERATIONS.

The plan of the work here described comprehended both qualitative and quantitative investigation of the responses of various agricultural plants to the application of chlorides in various nutrient media. As culture media the well-known nutrient solution of Knop (37) and also common soil were employed in the greenhouse, and certain experiments were conducted upon field plots. As indicated by the preceding review of previous experimentation, the effects of substances added to the soil in field experiments are liable to obscurity by uncontrolled climatic factors, as well as by soil peculiarities. Indeed, one of the prime desiderata of future experimentation in plant nutrition is the development of apparatus for the control of the chief climatic factors, to supplement the more refined methods of control now developed with artificial nutrient media.

The chlorides of potassium and sodium were chiefly used as sources of chlorine. Either the sulfate or nitrate of potassium, depending

upon the formula of nutrients employed, was replaced partly or wholly by potassium chloride, and sodium chloride was applied either alone or supplementary to a complete nutrient mixture.

The plants grown were chosen with a view both to their agricultural importance and to the including of a considerable range of genera, with supposedly different physiological requirements. Perhaps the most convenient descriptive treatment of the experimentation may be based upon the species of plants used, and the discussion to follow will conform to this plan. Results from preliminary cultures led to emphasis being placed upon the so-called root crops. These preliminary cultures were conducted with Knop's solution and Tottigham's (65) modification of the same, found somewhat better for the growth of young wheat plants. Inasmuch as the usual amount of MgSO_4 was replaced either wholly or in part by MgCl_2 and $\text{Mg}(\text{NO}_3)_2$ in these cultures, they must be considered as more or less deficient in an important nutrient element, namely, sulfur. Wheat, garden peas, and red clover were brought to a stage of apparent vegetative maturity in the various solutions employed, altho only the peas produced seed and neither of the other plants blossomed, even in the complete nutrient solution. Suffice it to state that the MgCl_2 was very toxic to the clover, but not to the other plants, as evidenced by the yields of dry matter. The remarkable fact about these cultures was that the maximum application of chloride led to a greatly increased length of roots. This increase ranged from 120 percent in the case of peas to 180 percent in the case of clover. Some corresponding increase in production of dry matter of the roots accompanied the greater elongation of these organs. That the elongation was due in part to the removal of a suppressing effect of MgSO_4 is evidenced by the fact that substitution of $\text{Mg}(\text{NO}_3)_2$ for the latter gave increased developments of roots, but the effects were not so pronounced as those produced by the chloride. In view of these results it appeared advisable to devote special attention to those plants in which the root comprised the major portion.

WHEAT.

Thus far, wheat (*Triticum sativum*) has been studied by the writer only in water culture, employing as a basis Knop's solution having a total salt concentration of 0.2 percent (osmotic value about 0.9 atm.) with KH_2PO_4 as the source of phosphorus. Uniform seedlings of the Fulcaster variety obtained by Shive's method (58, p. 343) were mounted by the method of the writer (65, p. 173-175) in

cylindrical glass jars of approximately 425 c.c. capacity (pint jars of the Mason pattern), each jar being covered with heavy brown paper to exclude light. The chlorine ion was introduced by replacing the KNO_3 of Knop's solution partially or completely with KCl , by adding NaCl to the unmodified solution, or by replacing the KNO_3 wholly with KCl and adding NaNO_3 , molecularly equivalent concentrations of these various salts being employed.⁴

Six different solutions were employed (see the column headings of Table 1), four cultures of each, each culture having three seedlings. During the growth of this culture series (February 16 to March 24, 1917, at Baltimore) the cultures stood on a rotating table of the type used by Shive (58, p. 344, 345), to equalize the aerial environment for all cultures of the series. The nutrient solutions were renewed after intervals of three days. At the end of the growth period the roots were washed and their approximate maximal lengths were measured. They were then severed from the tops and both roots and tops were weighed after drying at about 105°C . The volume of solutions absorbed by the plants during the last eight days of growth were also measured in this series.

As partial indices to the climatic conditions attending growth, temperature records were obtained by a thermograph placed in shade beside the rotating table, and the evaporating power of the air was determined by means of a white spherical porous-cup atmometer (43), the readings being reduced to those of the Livingston spherical standard. The average daily maximum temperature was 29.3°C ., the average daily minimum was 16.9° , and the extremes for the period were 31° and 10.5° . The total corrected loss from the atmometer for the culture period was 648.6 c.c.

Data of yield, root length, and water absorption appear in Table 1. From the data in this table it appears that increasing amounts of KCl depressed slightly the yields of dry tops and roots, as well as the length of roots. On the other hand, while the additions of NaCl and NaNO_3 seem to have depressed the length of roots equally, both led to slightly increased yields of dry matter as compared with the other solutions. The maximal application of KCl and the use of NaCl were attended by increased water absorption in proportion to the dry tops, but these increases were not so great as that produced where NaNO_3 was supplied, relative to the dry tops of the plants.

⁴ As here used the unmodified Knop's solution had the following volume-molecular partial concentrations of the respective salts: $\text{Ca}(\text{NO}_3)_2$, 0.0069; MgSO_4 , 0.0025; KH_2PO_4 , 0.0017; and KNO_3 , 0.0029. Four or five drops of a dense suspension of FePO_4 were added.

The slight effects of chlorides upon this plant, as here shown, are in agreement with the extensive results of Trelease (66).

TABLE 1.—*Effect of chlorides introduced into Knop's nutrient solution upon the growth of young wheat plants therein.*

Data.	Solution 1, unmodified Knop's.	Solution 2, 0.01 of KNO ₃ re- placed by KCl.	Solution 3, 0.1 of KNO ₃ re- placed by KCl.	Solution 4, total KNO ₃ replaced by KCl.	Solution 5, as 1 with addition of NaCl.	Solution 6, as 4 with addition of NaNO ₃ .
Dry weight of tops, mg.:						
Maximum.....	860	888	779	859	897	862
Minimum.....	750	693	726	626	761	742
Average.....	799	811	750	744	821	823
Dry weight of roots, mg.:						
Maximum.....	232	248	221	252	256	238
Minimum.....	207	195	204	175	216	216
Average.....	220	227	214	210	239	232
Greatest root length, mm.:						
Maximum.....	231	225	238	200	191	222
Minimum.....	200	216	200	153	178	178
Average.....	215	220	218	186	185	195
Water absorption, c.c.:						
Average per culture	293	288	286	305	348	374
Average per gram of dry tops.....	367	325	380	410	423	456
Average per deci- gram of dry roots	133	116	134	145	145	162

BUCKWHEAT.

The methods of culture applied to buckwheat (*Polygonum fagopyrum*) were those just described in connection with wheat, except that when the cultures were discontinued the leaves were severed at their junctions with the petioles and dried separately. This added procedure made possible a direct comparison of the rates of water absorption (as approximately measuring the transpiration ratio) with the dry weights of leaves. During the period of growth of these cultures (December 7, 1916, to February 6, 1917, at Baltimore), the climatic data obtained were as follows: Average maximum daily temperature 24.2° C., average daily minimum 15.2°, and extreme range from 30° to 8°. The corrected total evaporation for the period was 612.6 c.c., from the white spherical atmometer.

The data of this culture series appear in Table 2. Seed production is there expressed by an arbitrary method; 0 denotes that flowers only were produced; 1 denotes apparently immature seeds; and 2 denotes apparently mature seeds. From these relative scores an average value is shown for each nutrient solution.

TABLE 2.—*Effects of chlorides introduced into Knop's nutrient solution upon buckwheat grown to maturity therein.*

Data.	Solution 1, unmodified Knop's.	Solution 2, 0.01 of KNO ₃ re- placed by KCl.	Solution 3, 0.1 of KNO ₃ replaced by KCl.	Solution 4, total KNO ₃ replaced by KCl.	Solution 5, as 1 with addition of NaCl.	Solution 6, as 4 with addition of NaNO ₃ .
Dry weight of leaves, mg.:						
Maximum.....	1,293	1,454	1,319	1,096	1,079	1,168
Minimum.....	878	911	972	807	557	646
Average.....	1,128	1,063	1,124	956	841	937
Dry weight of stems, mg.:						
Maximum.....	1,332	1,552	1,419	1,480	1,253	1,307
Minimum.....	1,091	1,022	1,151	955	525	771
Average.....	1,181	1,199	1,273	1,135	936	1,101
Dry weight of roots, mg.:						
Maximum.....	194	171	216	164	180	142
Minimum.....	117	135	139	118	46	88
Average.....	154	154	173	131	119	114
Greatest root length, mm.:						
Maximum.....	241	230	235	266	223	282
Minimum.....	190	177	196	137	142	150
Average.....	214	211	216	192	179	192
Average water ab- sorption, c.c.:						
Per culture.....	248	225	238	210	160	200
Per gram of dry leaf	220	212	212	220	190	214
Per decigram of dry root.....	161	146	138	160	135	176
Seed production score	1.2	1.2	1.0	.8	1.0	1.0

From Table 2 it is evident that the maximal applications of chlorine depressed the production of dry matter in leaves and roots in all cases. The dry weight of the leaf tissue was decidedly lowest where NaCl was present in the solution, and this particular solution also produced the least dry matter of stem and petiole, but root length was quite uniformly depressed in all cultures that received the maximal amount of chlorine. No significant differences in seed production were apparent.

With the exception of the culture which received NaCl the amount of water absorption per unit of dry matter in the leaves was quite constant. This particular salt seems to have caused a specific reduction in transpiration. The ratio of water absorption to dry weight of roots varied irregularly, but root length and water absorption per culture varied in a corresponding manner, greater absorption accompanying longer roots.

From these considerations it appears that the chlorine ion in these cultures produced disturbances evident as decreased root length, de-

creased production of dry matter of leaves and roots, and decreased water absorption per culture. In some of these ways sodium chloride appears to have produced specific effects, such effects being least production of dry matter in both leaves and stems and the only variation from uniformity in the ratio of water absorption to foliar dry matter.

On the basis of the theory of electrolytic dissociation (47, bk. 2, chap. 7), according to which the salts as here employed should be almost completely dissociated into their constituent ions, it seems difficult to conceive appreciable chemical or physical differences between the culture solutions of formulas 5 and 6, Table 2. Nevertheless, the buckwheat plants exhibited in solution 5, to which sodium chloride was added, a response markedly different from that observed in solution 6, which received the same amounts of sodium and chlorine (but supplied in different salts) as did the former solution. In view of the current chemical interest in the relative rôles of molecules and ions in reactions (1), the apparently specific effects of the sodium chloride molecule here observed surely merit further investigation.

RADISH.

A single series of soil cultures was conducted in the greenhouse at Madison with a small, round variety of radish (*Raphanus sativus*) designated as Earliest Scarlet Turnip. Miami silt loam was employed in cylindrical stoneware jars 12 cm. deep and 18 cm. in diameter (of 1 gal. U. S. capacity), capable of holding 5 kg. of air-dried soil. The latter was secured to a depth of 3 to 4 inches from the University of Wisconsin farm, and was passed through a wire screen having meshes 6 mm. square. It then contained about 15 percent of moisture, and analysis by the standard methods (78) showed it to have the following partial composition, upon the oven-dried basis: Total nitrogen, 0.15 percent; total phosphorus, 0.06 percent; total potassium, 1.83 percent; CaCO_3 , 0.33 percent; humus, 1.38 percent.

The plan of fertilizing included both the substitution of KCl for K_2SO_4 in a complete fertilizer mixture and the supplementary addition of NaCl, chemically equivalent amounts of these salts being employed. Of the several salts the following amounts were employed per jar: 2.0 gm. $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$, 2.05 gm. K_2SO_4 , 1.76 gm. KCl, and 1.38 gm. NaCl. Two grams NaNO_3 was also added in dissolved portions as the plants developed. This rate of application has been found about 70 percent optimal for these proportions of salts in the growth

of rape under similar cultural conditions. A glass tube 2 cm. in diameter and about 13 cm. long, fixed upright in the soil, provided for aeration and subsurface watering. By daily weighings, the moisture content of the soil was kept at about 50 percent of saturation, as determined by Hilgard's method (29, p. 208, 209), or at about 25 percent on the basis of the weight of the dry soil. Distilled water was used. Eight plants per jar were grown to the first phase of maturity (February 24 to April 19, 1915), as indicated by the death of the basal leaves.

TABLE 3.—*Effects of chlorides introduced into the fertilizer treatment of radish, carrot, and parsnip grown from loam soil in the greenhouse.*

Data.	Complete, K as K ₂ SO ₄ .			Complete, K as KCl.			Complete, K as K ₂ SO ₄ , plus NaCl.		
	No. 1.	No. 2.	Aver- age.	No. 3.	No. 4.	Aver- age.	No. 5.	No. 6.	Aver- age.
Yield of air-dry tops, gm.:									
Radish.....	8.4	9.1	8.8	10.3	9.9	10.1	10.2	10.4	10.3
Carrot.....	10.3	9.9	10.1	11.7	14.0	12.9	11.2	11.5	11.4
Parsnip.....	25.7	23.6	24.7	26.3	23.3	24.8	21.9	20.5	21.2
Yield of oven-dry roots, gm.:									
Radish.....	9.4	9.3	9.4	9.6	9.1	9.4	10.4	10.0	10.2
Carrot.....	9.3	11.6	10.5	14.1	12.2	13.2	13.6	13.6	13.6
Parsnip.....	44.2	38.0	41.1	35.0	37.3	36.2	25.9	28.7	27.3
Dry matter in fresh roots, percent:									
Radish.....			5.8			5.9			5.4
Carrot.....			11.8			11.6			11.4
Parsnip.....			23.7			21.0			21.5
Sugars in dry roots, percent:									
Glucose:									
Radish.....			16.4			13.4			13.3
Carrot.....			17.3			19.6			18.9
Parsnip.....			5.8			3.7			3.0
Sucrose:									
Radish.....			4.1			3.7			7.5
Carrot.....			19.1			19.7			22.5
Parsnip.....			86.2			22.6			22.5

Determinations were made of the sugar contents of the radish roots. In attempting to extract the sugars from the dried, powdered roots of the sugar beet it had been found that the hot alcoholic extraction applied by Stone (61, p. 12) to cereal grains gave incomplete results, even when several times repeated. A modified method was therefore adopted. The dried and powdered roots were first extracted with water, then the aqueous extract was evaporated nearly to dryness and the sugars were removed by subsequent extraction

with alcohol of about 90 percent strength, as diluted by the aqueous residue. After removal of the alcohol and the preparation of the aqueous solution of the sugars the reducing power of the latter, before and after inversion with HCl, was determined, following the Defren-O'Sullivan method (56, p. 74-76). The reducing sugar and invert sugar contents, computed from the reducing power (56, Table 7) probably represent chiefly glucose and sucrose respectively, and they are so designated in the present report.

The results of these tests with radish are given in Table 3, which also presents the corresponding results for carrot and parsnip, to be referred to later. The application of the chlorides seems to have increased the yield of air-dried leaves of the radish, while only NaCl thus affected the dry matter of the root. The chloride led also to the production of a more watery root. As regards the percentage of sugars in the dry matter of the root, both chlorides somewhat depressed glucose, while NaCl led to an increase of sucrose.

CARROT.

A short-rooted variety of carrot (*Daucus carota*) of unknown name was grown to apparent maturity (May 10 to July 6, 1915, at Madison) in the pots of soil which had produced the radish roots just described, each pot supporting seven plants. The original fertilizer application was repeated, but the moisture of the soil was maintained at only 40 percent of saturation. The data of yields and analyses appear in Table 3.

It is apparent that both chlorides stimulated the production of dry matter in the roots of this plant and, to a less degree, in the tops. The percentage of dry matter in the roots was but slightly reduced by the application of chlorides. While the percentage of glucose was increased by both chlorides, only NaCl enhanced the production of sucrose.

PARSNIP.

In view of the genetic relationship of the parsnip (*Pastinaca sativa*) to the carrot it was considered of interest to test its response to chlorides. The cultures were conducted in boxes of cypress wood, 30 cm. long, 12.5 cm. wide, and 25 cm. deep, conveniently holding 15 kg. of silt loam. Fertilizers were applied as for radish and carrot, but the water supply was not controlled by weighing. A short, round variety of parsnip was employed (January 6 to June 10, 1916, at Madison), three plants in each culture. The data appear in Table 3.

Toxic effects of the chlorides were pronounced with this crop as regards the yield of roots, but the growth of tops suffered only from NaCl. Both chlorides produced more watery roots than did the chlorine-free ration. It appears significant of specific disturbing effects upon metabolism that these more watery roots were decidedly deficient in glucose and seriously depressed in sucrose, as percentages of the dry matter. In these respects the results for parsnip contrast sharply with those for carrot.

SUGAR BEET.

Greenhouse Tests.—The Vilmorin's Improved variety of sugar beet (*Beta vulgaris*) was grown, at the rate of three plants to the culture, in the deep wooden boxes previously described. Series 1 received salts at half the rates specified for the parsnip. In this series NaCl was applied alone, but not supplementary to a complete fertilizer. Series 2 received the fertilizer ration specified for the parsnip. Its growth period extended from January 6 to June 16, 1915, while that of series 1 extended from October 29, 1915, to May 23, 1916, both at Madison. The data for both series appear in Table 4.

TABLE 4.—Effects of chlorides introduced into the fertilizer treatment of the sugar beet grown upon loam in the greenhouse.

Description of fertilizer.	Culture No.	Yield of air-dry tops.		Yield of oven-dry roots.		Dry matter in fresh roots.		Sugar in dry roots.			
								Glucose.		Sucrose.	
		Ser. 1.	Ser. 2.	Ser. 1.	Ser. 2.	Ser. 1.	Ser. 2.	Ser. 1.	Ser. 2.	Ser. 1.	Ser. 2.
		Gm.	Gm.	Gm.	Gm.	Gm.	Gm.	Pct.	Pct.	Pct.	Pct.
No fertilizer.....	1	20.0	...	52.4	...	...	...	...	...	...	...
Do.....	2	16.5	...	42.3	...	...	...	...	...	...	...
Do.....	Average	18.3	...	47.4	...	18.5	...	2.8	...	61.3	...
NaCl only.....	3	16.9	...	44.7	...	...	...	...	...	...	...
Do.....	4	19.9	...	57.2	...	...	...	...	...	...	...
Do.....	Average	18.4	...	51.0	...	17.7	...	3.3	...	60.3	...
Complete, K as K ₂ SO ₄ ..	5	27.2	30.5	62.6	34.2	...	...	...	...	...	...
Do.....	6	28.7	38.6	47.3	44.1	...	...	...	...	...	...
Do.....	Average	28.0	34.6	55.0	39.2	16.3	25.6	2.8	2.3	60.2	77.0
Complete, K as KCl....	7	32.7	43.7	82.4	61.4	...	...	...	...	...	...
Do.....	8	38.9	41.3	76.0	56.0	...	...	...	...	...	...
Do.....	Average	35.8	42.5	79.2	58.7	16.8	23.8	4.4	2.7	57.0	74.3
As 5 and 6, plus NaCl..	9	...	46.6	...	61.3	...	...	...	...	...	...
Do.....	10	...	45.7	...	52.3	...	...	...	...	...	...
Do.....	Average	...	46.1	...	56.8	...	24.0	...	3.3	...	60.7

The data for sugar beet show generally the same departures as those for carrot where chlorides were applied, namely, marked increase in yield of dry matter of roots and smaller increase in yield

of tops, increased percentage of water in the fresh roots, and increased percentage of glucose in the dry roots. The sucrose content, on the other hand, was somewhat depressed by the chlorides, altho the increased production of root more than compensated the slight reductions of sucrose in these roots.

Field Cultures.—The field tests of sugar beet were conducted with the application of common salt alone. The soil was Miami silt loam, previously referred to, which had received liberal applications of farm manure. Rectangular plots of one-eightieth acre (1×2 rods) were laid out upon a level area of a field planted to Lane's Improved variety of sugar beet, at Madison. Fine salt was applied broadcast at rates of 260 and 520 pounds per acre upon separate plots either in one application, 12 days after planting, or in two equal applications, 12 and 31 days after planting. The number of plants was reduced to 110 per plot 40 days after planting, this being the least number on any plot at the time. After recording the total weight of the freshly harvested roots, six beets were dried for analysis. The data on yields and composition appear in Table 5.

TABLE 5.—*Effects of adding NaCl to field cultures of sugar beet on loam soil fertilized with farm manure.*

Plot No.	NaCl added.	Yield of fresh roots.	Sugars in dry roots.	
			Glucose.	Sucrose.
		<i>Kilograms.</i>	<i>Percent.</i>	<i>Percent.</i>
1	None	90.0	1.7	65.0
2	1,590 gr. (2 applications)	115.0	4.4	61.2
3	795 gr. (do.)	103.6	4.1	71.2
4	1,590 gr. (1 application)	96.7	2.8	54.7
5	795 gr. (do.)	101.3	3.3	53.8
6	None	92.2	2.8	57.2

It will be seen from the data in Table 5 that the number of applications influenced the yield. Thus, although the higher amount of salt produced the least effect when applied as one dressing, it led to the highest yields when distributed between two applications. In a general way, the percentages of glucose increased with the yield of roots, but the percentage of sucrose was depressed by the salt in most cases, and particularly by the single applications. While this limited preliminary test gives little basis for conclusions it appears to justify more extended investigation of the problem involved.

POTATO.

Greenhouse Tests.—Greenhouse cultures of potato (*Solanum tuberosum*) were conducted at Madison in cubical boxes of cypress wood 1 foot deep, containing 20 kg. of Miami silt loam. In the completely fertilized cultures the following kinds and amounts of salts were added per box: NaNO_3 , 2.44 gm.; $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$, 2 gm.; and either K_2SO_4 , 3.2 gm., or KCl , 2.74 gm. These amounts of the potassium salts are chemically equivalent. In some cultures KCl replaced one-fourth, one-half, or three-fourths of the K_2SO_4 of the complete ration, and in other cases K_2SO_4 and KCl were applied alone at the maximum rate of the complete ration. NaCl was similarly employed, as is indicated in Table 6. One of each pair of duplicate cultures, of the Triumph variety, received 8 gm. of CaCO_3 . As already intimated, the rations were so manipulated that the various applications of potassium salts supplied the same amount of potassium, and the same was true of the chlorine supplied by the chlorides.

One plant per culture was grown from a cubical cutting about 2.5 cm. thick. Distilled water was supplied as the appearance of the soil indicated need, and each series was harvested as soon as all the tops appeared mature. All tubers less than half an inch in diameter were discarded and the remainder were sliced and dried at 55°C . Starch determinations were then made by the standard method of the American agricultural chemists (78, p. 53.)⁵ Filtered saliva was employed as the hydrolizing agent, and the glucose finally produced was determined in the manner already described. No correction was made for the small amount of reducing sugars probably present in the tubers.

In Table 6 the average data for duplicate cultures are given thruout, as liming was found to produce no specific effects upon either yield or composition of the tubers. In series 1, the Triumph variety was grown, and tubers from this series were employed as seed for series 2. Series 3 was grown in a sandy soil from Spooner, Wis., but in all other cases Miami silt loam was employed. Series 4 was conducted with the Rural New Yorker variety.

While the limited data of Table 6 do not justify conclusive statements they indicate superiority of KCl over K_2SO_4 in the complete fertilizer, relative to percentage and total yield of dry matter in the tubers. As regards percentage of starch the Triumph variety was in-

⁵ Comparative trials had shown the measurement of starch by specific gravity of the tubers to be unreliable. This result is confirmed by Watson (Va. Agr. Expt. Sta. Bul. 55, 1905) and by Morrison (unpublished thesis for degree of B.Sc., Univ. of Wis., 1911.)

different to KCl, while the Rural New Yorker was depressed thereby, in the completely fertilized cultures. Judged by all three of the criteria employed, both potassium salts were detrimental when applied alone to the late variety of potato, but KCl the more so, as compared with the unfertilized cultures. It does not appear that NaCl was particularly injurious to the Triumph variety, excepting the production of more watery tubers, as compared with the unfertilized controls. In the latter respect, however, its results fall short of those of the complete fertilizer. Evidently the variety of potato is a more determinate factor than the type of soil in the effects of chlorides observed under these conditions.

TABLE 6.—*Effects of chlorides upon the yield and composition of potato tubers grown in soil cultures in the greenhouse.*

Data.	No ferti- lizer.	Complete.					K ₂ SO ₄ only.	KCl only.	NaCl only.
		All potas- sium as K ₂ SO ₄ .	0.75 of potas- sium as K ₂ SO ₄ , 0.25 as KCl.	0.50 of potas- sium as K ₂ SO ₄ , 0.50 as KCl.	0.25 of potas- sium as K ₂ SO ₄ , 0.75 as KCl.	All potas- sium as KCl.			
Number of tubers per culture:									
Series 1.....	2	3	3	3	4	3	.....	.....	2
Series 2 ^a	6	5	1	6	3	7	.....	.....	2
Series 3.....	1	3	.....	.....	.....	3	.....	.....	1
Series 4.....	3	4	4	4	3	4	4	2	.....
Yield of air-dry tubers, gm.:									
Series 1.....	5.7	9.0	9.9	11.8	16.9	16.5	.....	.....	7.1
Series 2 ^a	27.4	71.8	1.2	71.8	36.0	91.0	.....	.....	6.1
Series 3.....	7.5	8.1	.....	.....	.....	6.6	.....	.....	7.3
Series 4.....	11.9	11.7	9.8	8.9	8.6	13.2	9.9	5.9	.....
Air-dry matter in fresh tubers, percent:									
Series 1.....	24.2	21.8	20.4	21.3	22.1	23.7	.....	.....	23.2
Series 3.....	25.5	15.9	.....	.....	.....	17.2	.....	.....	19.1
Series 4.....	24.6	20.7	18.1	22.1	21.1	22.8	20.9	18.8	.....
Starch in dry mat- ter, percent:									
Series 1.....	80.0	74.0	.....	.....	.....	75.3	.....	.....	78.5
Series 3.....	75.3	75.8	.....	.....	.....	78.3	.....	.....	75.3
Series 4.....	77.4	78.6	77.7	72.6	71.3	70.5	73.2	71.7	.....

^a The data for this series are for fresh tubers instead of air-dry ones.

Field Cultures.—Field tests of chlorides upon the potato were conducted at Madison, with a basal fertilizer ration per acre of 160 pounds of NaNO₃, 400 pounds of acid phosphate, and 200 pounds of K₂SO₄. KCl was substituted for K₂SO₄ by intervals of one-fourth of the full amount of potassium, as in the greenhouse cultures. In addition to an unfertilized plot, NaCl was applied alone at the rate of 136 pounds

per acre, equivalent to the maximum application of KCl in the complete fertilizer. The plots were of the shape and size employed for the sugar beet, but they were laid out permanently with alleys 3 feet in width between adjacent plots. NaNO_3 was broadcasted over the plots in two applications as the plants developed, but the other fertilizers were applied with the drill. Series 1, Triumph variety, matured in 111 days, with a severe drouth from the 38th to the 108th day. Series 2, Rural New Yorker variety, matured in 127 days, but a prolonged period of heavy rains near the close of this period caused excessive loss of the tubers by decay. The crop of series 1 was divided into marketable and unmarketable tubers, the former weighing 65 gm. or more each. Six tubers of average size were selected from this lot for analysis. Only the two marginal and two middle rows of each plot were dug in series 2. Twelve representative tubers were then taken for cooking tests⁶ and for analysis. All of the data here referred to are presented in Table 7.

TABLE 7.—*Effects of chlorides upon the yield and composition of potato tubers grown on field plots.*

Description of fertilizer.	Market- able tubers, series 1.	Yield of air-dry tubers, series 1.	Dry matter in fresh tubers.		Starch in dry matter.		Relative score of cooking quality.	
			Ser. 1.	Ser. 2.	Ser. 1.	Ser. 2.	Boiling.	Baking.
No fertilizer.....	Pct. 45	Grams. 3,270	Pct. 19.2	Pct. 20.7	Pct. a71.8	Pct. b80.1	5	6
Complete, all potassium as K ₂ SO ₄	49	4,310	18.4	20.6	72.3	81.0	3	2
Complete, 0.75 of potassium as K ₂ SO ₄ , 0.25 as KCl...	39	4,470	20.4	20.4	.....	.....	2	3
Complete, 0.5 of potassium as K ₂ SO ₄ , 0.5 as KCl....	44	4,270	18.6	19.7	.....	.....	4	4
Complete, 0.25 of potassium as K ₂ SO ₄ , 0.75 as KCl...	48	4,150	18.1	20.4	.....	.....	6	5
Complete, all potassium as KCl.....	53	4,120	18.5	21.0	73.4	79.9	1	1
NaCl only.....	35	2,650	18.1	20.0	71.4	79.7	7	7

^a Mother tubers contained 72.4 percent of starch.

^b Mother tubers contained 75.7 percent of starch.

In series 1 (Triumph variety) the higher amounts of KCl in the complete fertilizer appear to have depressed the yield of dry matter, while NaCl exerted this effect decidedly, as compared with the unfertilized plot. The only significant departure from a uniform percentage of marketable tubers seems to have been the decline due to

⁶ Performed by Miss Ada Hunt, of the Home Economics Department of the University of Wisconsin.

NaCl. While KCl was without effect upon the percentage of dry matter in the tubers of either series, NaCl alone seems to have slightly decreased this value. No significant variations in the percentage of starch resulted from the varied fertilizer treatment. In cooking quality the tubers produced by the fertilizers containing the greater proportions of K_2SO_4 were generally superior to those receiving more KCl, but those receiving potassium entirely as KCl scored first by both tests. There was no doubt of inferiority of the tubers produced with NaCl alone, these being particularly characterized by the judges as "of a bitter, alkaline flavor."

While these results indicate that chlorides influence the yield of the potato tuber much more than they affect its composition, their chief value appears to lie in the results they promise for more extended investigation along the lines indicated here.

Succeeding field crops have apparently benefited from the chlorides applied to the potato crops just described. Following the Rural New Yorker potatoes, the plots were sown to barley (*Hordeum vulgare*) and common red clover (*Trifolium pratense*). In the following year (1916), the yield of barley grain on the unfertilized plot was 10.5 pounds, while on the plots which had been completely fertilized for the potatoes it ranged from 12.5 to 16.0 pounds, and where NaCl had been applied alone it amounted to 15.0 pounds. The ratios of grain to straw for these respective treatments were 0.45, 0.45 to 0.52, and 0.56, respectively. The yield of grain and the ratio of grain to straw increased with the proportion of KCl in the rations of the completely fertilized plots. In the following year (1917), the yields of clover hay were 45 pounds for the unfertilized plot, 56 to 60 pounds for the completely fertilized plots, and 63 pounds for the plot which had received NaCl only. The yields were practically the same whether K_2SO_4 or KCl had been applied in the complete fertilizer.

THE MECHANISM OF CHLORINE EFFECTS.

NATURAL SUPPLY.

In considering the possible use of chlorides as fertilizers it is important to take account of the supply of chlorine in the soil. There is also some acquisition of this element in the rainfall, although a portion of this supply doubtless circulates within local areas of soil and atmosphere.

The following chlorine-bearing minerals, soluble in water or dilute acids, appear to occur commonly in soils (3, p. 182; 50, p. 48), namely: Halite (NaCl), sylvite (KCl), apatite [$Ca_4CaClF(PO_4)_3$], and

sodalite $[\text{Na}_4(\text{AlCl})\text{Al}_2(\text{SiO}_4)_8]$. Few, if any, soil analyses give data on the total chlorine content of the soils concerned. Preliminary attempts to secure such data in the present study by the method of alkaline fusion (30, p. 184) encountered difficulties, but a number of determinations of water-soluble chlorine were made upon air-dried samples of soils pulverized to pass a sieve having 100 meshes to the inch. Extracts of 25 grams of soil in 400 cc. of water, obtained by agitation for two hours at 17°C ., were filtered as clear as possible through double filter papers (Schleicher and Schull paper No. 595) and washed to a volume of 500 c.c. Chlorine was determined in 200 c.c. aliquots of the solution, in the manner recommended by Hillebrand (30, p. 183). The results appear in Table 8.

TABLE 8.—*Content of water-soluble chlorine in air-dried Wisconsin soils.*

Type of soil,	Chlorine, percent in air-dry soil.	Chlorine, pounds per acre foot. ^a
Miami loam.....	0.005	150
Lancaster loam.....	0.009	270
Superior Clay.....	0.008	240
Spooner sand.....	0.005	175
Peat (University marsh).....	0.019	380

^a The following values were ascribed per acre-foot of air-dry soil: Peat, 2,000,000 pounds; loam and clay, 3,000,000 pounds; and sand, 3,500,000 pounds.

From the data given by Hopkins (32, Tables 23, 131b) the annual removal of chlorine per acre by common crops may be calculated to range approximately from 5 pounds in cereal grains (seed only) to 50 pounds for the sugar beet (root only). Tobacco ranks high as a chlorine-absorbing plant, the leaves and stems accumulating 125 pounds of the element per acre, in some cases. Hays and straws account for the annual removal of about 30 pounds of the element per acre. These considerations indicate the inadequacy of the soil supply of chlorine for maintaining the usual plant content of the element in cropping systems.

Leaching is apparently a more serious factor than cropping in the annual depletion of soil chlorides, but both are partly compensated by the chlorine compounds washed to the soil in rain. At the Rothamsted Experiment Station, Lawes, Gilbert, and Warington (40, p. 263-266, 346, 347) found the loss of chlorine in subsurface drainage waters to be approximately equal to the supply from rain, fluctuating with the latter. As remarked by these authors, the chlorine content of rain usually decreases with the distance from the ocean. The annual supply per acre at Rothamsted was found to be 13.4 pounds, the

content per unit of precipitation being about 2.5 times as great in winter as in summer. Vituynii (67) reports average annual precipitations per acre of from 7.4 to 20.5 pounds of chlorine at eight Russian stations; and Knox (38) found a corresponding fall of nearly 37 pounds at Mt. Vernon, Iowa, during only eight months, from summer to spring. The latter unusual observation may be explained by supposing that chlorides had been transported by wind from the arid regions farther west.

In the present investigation 30 inches of rainfall for the period from July to September, inclusive, 1915, contained 5.9 pounds of chlorine per acre, while 43 inches of precipitation for the period from July to October, inclusive, 1917, contained 6.3 pounds of chlorine. From November to January, inclusive, 1917-18, 36 inches of snowfall (equivalent to 3.5 inches of rain) contained 1.7 pounds of chlorine. At these rates the total annual atmospheric supply of chlorine per acre at Madison is approximately 16 pounds, equivalent to 26 pounds of NaCl. This value probably exceeds the average, for the partial rainfall examined in 1915 was equal to the normal annual precipitation for this region. For the periods here observed the chlorine supply per acre-inch of precipitation in equivalents of rain is about 0.2 pound for rain and 0.5 pound for snow, which agrees with the findings at Rothamsted. The higher chlorine supply of the winter months may be due to an inclusion of wider areas by storms in the drier atmosphere of these months, as compared with summer, more distant sources of the element thus being brought into play. Increased combustion of fuel might also enhance the atmospheric supply of chlorine in winter.

From the foregoing consideration it appears that the chlorine content of soils in humid regions tends toward a minimum, the magnitude of which is largely determined by the chlorine content of the rainwater and the nature of the crops removed. If a certain chloride content of the soil is essential for the best production of some crops it is quite possible, and even probable, that the value of this minimum may be too low. Under these conditions the use of common salt in conjunction with the usual fertilizers should become a practical consideration, as indicated by some of the results considered above.

EFFECTS OF CHLORIDES UPON THE SOIL.

It has been contended by various authorities that sodium chloride may favor plant growth by liberating potassium. The results of Schulze (54) seem to indicate quite conclusively, however, that this effect is not universally important. To one portion of a sand-loam

mixture he added a potassium-containing zeolite, to another portion the zeolite was applied with sodium chloride, and a control portion was left untreated. Both treated soils gave greater yields of white mustard than did the control. The yield where NaCl was applied was about twice as great as where the zeolite was used alone, but the potassium content of the plants was the same from the two fertilizer treatments. From these results Schulze concluded that sodium served directly as a plant nutrient.

Experiments with oats led Soderbaum (60) to believe that NaCl acted directly upon the plant by virtue of its chlorine content. He employed three portions of a soil deficient in chlorine, to each of which was added a complete fertilizer containing one of the following salts as a source of nitrogen, namely, NaNO_3 , $(\text{NH}_4)_2\text{SO}_4$, and NH_4Cl . Sodium chloride, equivalent in amount to the NaNO_3 used, was added to similarly fertilized portions of the soil. The total yield was increased by NaCl, when this was added with the first two sources of nitrogen, but not when it was added with NH_4Cl . Hence the benefit derived from NaCl was thought to be specifically due to its chlorine content.

There remains the possibility of indirect action of chlorides upon plant growth, as by influencing the soil flora in such manner as to alter the fertility of the soil. In this connection it may be mentioned that C. B. Lipman (41) found NaCl toxic to ammonifying bacteria, but stimulating to nitrifying and nitrogen-fixing organisms, at rates of application from 0.05 to 0.5 percent, on the basis of dry weight, in a sandy soil. Greaves (20) observed stimulation of ammonification in a sandy soil by NaCl at a concentration of about 0.01 percent, although the salt was toxic at twice that concentration. Greaves' smaller application is equivalent to about 350 pounds of salt per acre-foot of soil, an amount found favorable in the fertilizing tests already described. Other chlorides differed widely from NaCl in their effects on ammonification, as noted by Greaves. He states that the same concentration of sodium chloride is required to reduce ammonification and the yield of wheat in the field, each to half the normal value. It seems, from the preceding citations, that chlorides may affect the growth of higher plants by altering the biological production of available nitrogen compounds in the soil. Nevertheless, from the known limited influence of fertilizers upon the composition of plants and in view of the variable response of different plant species to the application of chlorides under similar conditions, this supposition seems quite inadequate to explain the changes of plant composition produced by these salts.

POSSIBLE MECHANISM OF CHLORINE EFFECTS WITHIN THE PLANT.

Nothing is known as to how NaCl and other chlorides may bring about such physiological responses in plants as are here mentioned. Many physiological responses to the presence of inorganic salts have been regarded by Loeb (44, p. 78-95) and others as due to changes in ion-protein compounds within the living protoplasm. In his theory of ion-protein compounds Loeb postulates the formation and disruption of such compounds by enzyme action. Livingston (42, p. 22, 23) has advanced a somewhat similar hypothesis to account for the toxicity and stimulating influence of certain metals to plants. If chlorine is involved in organic compounds of the plant these must be very unstable. Evidence to this end is furnished by the work of Schmidt (53), who found the entire chlorine content of sugar beet seed to be soluble in water and capable of direct precipitation by AgNO_3 . This may be regarded as strong evidence of the absence of any considerable amounts of organic chlorine compounds in this seed. It therefore appears probable that the chlorine of the sugar beet, and perhaps of other plants, exists in the cells largely as inorganic chlorides, comparable to those absorbed from the soil.

The apparent relation of chlorine content to accumulation of starch in the potato tuber (Pfeiffer *et al.*, 49) suggests enzyme activity as a main controlling condition for this effect. That chlorides which may readily exist in plant cells greatly accelerate the action of ptyalin of the human saliva is clear from the work of Wohlgemuth (77). Cole (14) obtained similar results with ptyalin, but found that the action of invertin was considerably retarded by NaCl. Stimulation of diastatic enzymes from plant sources by the action of chlorides has been observed by Kellerman (36) and by Hawkins (28).

If, supported by the foregoing evidence, we suppose that the concentration of chlorides in the cell may exert marked controlling influence upon the activities of intracellular enzymes, especially the diastatic ones, and if we suppose that many vital activities of the plant are controlled in their turn by enzyme action, we arrive at a general suggestion of a possible way by which variations in the concentration of these salts may bring about such physiological responses as have been observed. This hypothesis is, of course, very general in its nature and only tentative, but it may serve to connect the various facts as we know them at present. As more information accumulates this suggestion may be elaborated, modified, or discarded, as may be determined.

SUMMARY.

A survey of previous field and greenhouse investigations of the effects of chlorides upon the growth and composition of plants discloses extremely variable results. It is apparent that the species of plant, the type of soil, and especially the complex of factors considered as climate, greatly influence these effects.

In the present investigation the introduction of potassium and sodium chlorides into water cultures but slightly affected wheat plants during the first five weeks after germination. Buckwheat grown to apparent maturity in similar cultures was decidedly affected by the application of these chlorides. Although seed production remained apparently undisturbed, the length of roots and the yield of dry matter was depressed. The least production of dry matter in leaf blades and the greatest depression of water absorption per unit of dry matter of the foliar tissue occurred in the presence of sodium chloride.

The radish responded only slightly, in yield and composition, to the application of potassium and sodium chlorides along with complete fertilizer in soil cultures in the greenhouse. Under similar conditions, increased production of dry matter and of the percentages of sugars therein resulted with the carrot, while the reverse was true of the parsnip. In the latter case sodium chloride was particularly injurious.

The sugar beet gave the same general responses to chlorides as did the carrot, when grown in the greenhouse. While the roots were more watery where chlorides were applied, the yield of dry matter was greatly increased. The dry matter of such roots contained more glucose, but less sucrose, than that obtained from cultures in soil not receiving chlorides. Similar responses followed the application of common salt alone to beets grown in the field.

The potato produced increased yields of dry matter in the tuber when potassium chloride was supplied in place of potassium sulfate, in a complete fertilizer ration, to soil cultures in the greenhouse. Relative to the percentage of starch, the Rural New Yorker and Triumph varieties of potato responded differently, the former being depressed while the latter was unaffected. The results indicated that the variety of plant was more important than the type of soil in determining this effect of chlorides. In field cultures in a dry season the application of potassium chloride in a complete fertilizer decreased the yield of dry matter in the tubers, but not the percentage of marketable tubers, of the Triumph variety. In a season which was very humid toward its close, no significant differences in composition

or cooking quality were found between tubers of the Rural New Yorker variety produced where potassium sulfate and potassium chloride were employed separately in a complete fertilizer ration. Sodium chloride applied alone altered the composition of the tubers only slightly in this test, but affected their quality seriously.

Determinations of the water-soluble chlorides in several types of Wisconsin soils have shown them to be equivalent to about 150 to 380 pounds of chlorine per acre-foot. It is shown that this supply is inadequate for long maintaining the usual plant content of the element in crop rotations. The annual supply of chlorine in rain and snow at Madison is about 16 pounds per acre, but, judging from conditions at the Rothamsted Experiment Station, this acquisition is probably counterbalanced by losses in drainage waters.

Evidence is cited which indicates that sodium chloride serves directly as a fertilizer, and that chlorine is the active element therein. Further evidence indicates a possible rôle of chlorides in stimulating the biological production of available nitrogen compounds in the soil, but this effect seems inadequate for explaining all of the varied responses of higher plants to the application of chlorides.

Proceeding from the observed effects of chlorides upon diastase and other enzymes which act upon carbohydrates, a tentative hypothesis is advanced to explain the varied physiological responses of plants to chlorides through regulation of enzyme activity by these salts.

On the whole, it appears quite possible that further investigation may lead to the development of practical rules for the use of chlorides in agriculture in such ways as to increase and improve certain crops, due account being taken of those crops injured by these salts, as well as of climatic and soil conditions.

LITERATURE CITED.

1. ACREE, S. F. Reactions of both the ions and non-ionized forms of electrolytes. *In Amer. Chem. Jour.*, 49: 345-368. 1913.
2. ASCHOFF, C. Über die Bedeutung des Chlor in der Pflanze. *In Landw. Jahrb.*, 19: 113-141. 1890.
3. BAYLEY, W. S. Minerals and Rocks, 227 p. New York and London, 1915.
4. BEYER, A. Versuche über die Bedeutung des Chlor. *In Landw. Vers. Stat.*, 11: 263-267. 1869.
5. BOLIN, PEHR. Sodium chloride as a fertilizer. *In Chem. Abs.*, 10: 2268, 2269. 1916.
6. BROOKS, W. P., and THOMSON, H. M. Sulphate compared with muriate of potash for various crops. *In Ann. Rpt. Hatch Expt. Sta. Mass. Agr. Coll.*, 12: 25-28. 1900. Idem. The relative value of muriate and sulphate of potash. *Ibid.*, 13: 96-98. 1901.

7. ——. The relative merits of muriate and sulphate of potash. *In* Ann. Rpts. Hatch Expt. Sta. Mass. Agr. Coll., 12: 25-28, 1900; 14: 17-20, 23, 24, 1902; 15: 113-118, 1903; 17: 125-131, 1905.
8. ——. The relative value of muriate and high-grade sulphate of potash. *In* Hatch Expt. Sta. Mass. Agr. Coll. 13th Ann. Rpt., p. 96-98. 1901.
9. ——. The relative value of muriate and sulphate of potash for garden crops. *In* Hatch Expt. Sta. Mass. Agr. Coll. 14th Ann. Rpt., p. 23, 24. 1902.
10. ——. Comparison of different potash salts for field crops. *In* Hatch Expt. Sta. Mass. Agr. Coll. 16th Ann. Rpt., p. 128-132. 1904.
11. —, CHURCH, F. R., and HASKELL, S. B. Relative value of muriate and sulfate of potash. *In* Hatch Expt. Sta. Mass. Agr. Coll. 18th Ann. Rpt., p. 15-46. 1906.
12. CAMERON, FRANK K. The Soil Solution, the Nutrient Medium for Plant Growth, vi + 136 p. Easton, Pa., 1911.
13. CARRUTHERS, WM., and VOELCKER, J. AUGUSTUS. A second report by the consulting botanist and consulting chemist on grass experiments conducted by the society. *In* Jour. Roy. Agr. Soc. England, 3d ser., 2 (whole ser. 61): 116-138. 1891.
14. COLE, W. S. Contributions to our knowledge of the action of amylolytic ferments. *In* Jour. Physiol., 30: 202-220. 1904. *Idem*. The influence of electrolytes on the action of invertin. *Ibid.*, 30: 281-289. 1904.
15. DAVIDSON, R. J. The influence of commercial fertilizers upon the quality of the Irish potato. *Va. Agr. Expt. Sta. Bul.* 92, p. 97-108. 1898.
16. DERUIJTER DE WILDT, J. C., MOL, D., and BERKHOUT, A. D. Experiments on the influence of common salt and green manuring on the yield and composition of the sugar beet, together with their residual effect. *Abs. in Expt. Sta. Rec.*, 26: 438. 1912.
17. DYER, BERNARD. Field experiments with cabbages. *In* Jour. Roy. Agr. Soc. England, 2d ser., 23: 425-430. 1887.
18. EMERY, F. E. Which element of fertility is dominant for potatoes? *In* N. Y. State (Geneva) Agr. Expt. Sta. 9th Ann. Rpt., p. 379-383. 1890.
19. GONEHALLI, V. H. Common salt and its use as manure in the Konkan division. *Bombay Dept. Agr. Bul.* 29, 19 p. 1914.
20. GREAVES, J. E. The influence of salts on the bacterial activities of the soil. *In* Soil Sci., 2: 443-480. 1917.
21. GRIFFITHS, A. B. A Treatise on Manure, or the Philosophy of Manuring, xv + 399 p. London, 1889.
22. HALL, A. D. Fertilizers and Manures, xv + 384 p. Edinburgh, 1910.
23. HANNAM, JOHN. Experiments with salt and other manures upon oats, barley and wheat. *In* Jour. Roy. Agr. Soc. England, 5: 267-276. 1844.
24. HANSTEEN, B. Über das Verhalten der Kulturpflanzen zu den Bodensalzen. *In* Jahrb. Wiss. Bot., 47: 289-376. 1910.
25. HARRIS, FRANK S. Effect of alkali salts in soils on the germination and growth of crops. *In* U. S. Dept. Agr., Jour. Agr. Research, 5: 1-53. 1915.
26. HARTER, L. L. The variability of wheat varieties in resistance to toxic salts. *U. S. Dept. Agr., Bur. Plant Indus. Bul.* 79, p. 35, 36. 1905.

27. —. The influence of a mixture of soluble salts, principally sodium chloride, upon the leaf structure and transpiration of wheat, oats, and barley. U. S. Dept. Agr., Bur. Plant Indus. Bul. 134, 22 p. 1908.
28. HAWKINS, L. A. The effects of certain chlorides singly and combined in pairs on the activity of malt diastase. *In Bot. Gaz.*, 55: 265-285. 1913.
29. HILGARD, E. W. Soils, Their Formation, Properties, Composition and Relations to Climate and Plant Growth in Humid and Arid Regions, xxix + 593 p. New York, 1912.
30. HILLEBRAND, W. F. The analysis of silicate and carbonate rocks. U. S. Geol. Survey Bul. 422. 1910.
31. HILLS, J. L., WHITE, B. O., and JONES, H. C. Effects of fertilizers on the composition of crops: Potatoes. *In Vt. Agr. Expt. Sta. 11th Ann. Rpt. (1897-98)*, p. 150-155. 1898.
32. HOPKINS, C. G. Soil Fertility and Permanent Agriculture, 653 p. New York, 1910.
33. JARIUS, M. Über die Einwirkung von Salzlosungen auf den Keimungsprocess der Samen einiger einheimischen Culturgewasche. *In Landw. Vers. Stat.*, 32: 149-178. 1886.
34. JENKINS, E. H. The comparative effects of muriate and sulphate of potash on the potato crop. *In Conn. (New Haven) Agr. Expt. Sta. 19th Ann. Rpt.*, p. 117-129. 1895.
35. JONES, L. R. The orange hawkweed, or "paintbrush." *In Vt. Agr. Expt. Sta. 10th Ann. Rpt. (1896-97)*, p. 62-74. 1897.
36. KELLERMAN, KARL F. The effects of various chemical agents upon the starch-converting power of taka diastase. *In Bul. Torrey Bot. Club*, 30: 56-70. 1903.
37. KNOP, W. Quantitative Untersuchungen über den Ernährungsprocess der Pflanzen. *In Landw. Vers. Stat.*, 7: 93-107. 1865.
38. KNOX, W. K. Nitrogen and chlorine in rain and snow. *In Chem. News*, 111: 61, 62. 1915.
39. LAWES, J. B. The action of common salt as manure. *In Jour. Roy. Agr. Soc. England*, 25: 512-521. 1864.
40. —. GILBERT, J. H., and WARINGTON, R. On the amount and composition of the rain and drainage waters collected at Rothamsted. *In Jour. Roy. Agr. Soc. England*, 2d ser., 17: 241-279; 311-350, 1881, and 18: 1-71, 1882.
41. LIPMAN, CHAS. B. Toxic effects of "alkali salts" in soils on soil bacteria. I. Ammonification. *In Centbl. Bakt., Abt. 2*, 32: 58-64. 1911. II. Nitrification, *ibid.*, 32: 305-313. 1912. III. Nitrogen fixation. *Idem.* and L. T. SHARP. *Ibid.*, 35: 647-655. 1912.
42. LIVINGSTON, B. E. Chemical stimulation of a green alga. *In Bul. Torrey Bot. Club*, 32: 1-34. 1904.
43. —. Atmometry and the porous cup atmometer. *In The Plant World*, 18: 21-30, 51-74, 95-111, 143-149. 1915.
44. LOEB, JACQUES. Concerning a theory of irritability and the rôle of Na, K and Ca for animal life. *The Dynamics of Living Matter*, xi + 233 p. New York, 1906.
45. LOEW, OSCAR. The physiological rôle of mineral nutrients in plants. U. S. Dept. Agr., Bud. Plant Indus. Bul. 45, p. 25, 26. 1903.

46. LYON, T. L., and WIANCKO, A. T. Experiments in the culture of the sugar beet in Nebraska. *Nebr. Agr. Expt. Sta. Bul.* 81. 1903.
47. NERNST, WALTER. Theoretical Chemistry (translation by Tizard), xix+810 p. London, 1911.
48. NOBBE, FRIEDRICH, and SIEGERT, THEODOR. Über das Chlor als Spezifische Nährstoff der Buchweizenpflanze. *In Landw. Vers. Stat.*, 4: 318-340, 1862; 5: 116-136, 1863; 6: 108-120, 1864; 7: 371-386, 1865; 8: 187, 188, 1866.
49. PFEIFFER, TH., FRANKE, E., LEMMERMANN, O., and SCHILLBACH, H. Über die Wirkung verschiedener Kalisalze auf Zusammensetzung und den Ertrag des Kartoffeln. *In Landw. Vers. Stat.*, 49: 349-385. 1898.
50. PIRSSON, LOUIS V. Rocks and Rock Minerals, iv+414 p. New York, 1913.
51. PLATE, F. The action of isolated chlorides on the germination period of *Avena sativa*. *In Chem. Abs.*, 9: 1070. 1915.
52. PRIANISHNIKOV, D. Results of vegetation experiments in the years 1901-1903. *Abs. in Expt. Sta. Rec.*, 18: 320, 321. 1906.
53. SCHMIDT, E. W. The effects of chlorides on plant growth. Unpublished thesis submitted for the degree of B.Sc., Univ. of Wis., Madison, 1915.
54. SCHULZE, B. Die Düngewirkung des Chlornatriums. *In Landw. Vers. Stat.*, 86: 323-330. 1915.
55. SHELTON, E. M. Experiments with wheat. *Kans. Agr. Expt. Sta. Bul.* 4, p. 45-48. 1888. Salt as a fertilizer. *Kans. Agr. Expt. Sta. Bul.* 7, p. 83-86. 1889. Salt as a fertilizer for oats. *Kans. Agr. Expt. Sta. Bul.* 29, p. 176, 177. 1891.
56. SHERMAN, H. C. Methods of Organic Analysis, 407 p. New York, 1912.
57. SHIVE, J. W. A three-salt nutrient solution for plants. *In Amer. Jour. Bot.*, 4: 157-160. 1915.
58. —. A study of physiological balance in nutrient media. *In Physiol. Researches*, 1: 327-397. 1916.
59. SHULOV, I. S. Various smaller experiments with fertilizers and soils. *Abs. in Expt. Sta. Rec.*, 22: 223, 224. 1910.
60. SODERBAUM, H. G. The fertilizing action of common salt. *Abs. in Expt. Sta. Rec.*, 26: 623. 1912.
61. STONE, W. E. The carbohydrates of wheat, maize, flour, and bread. *U. S. Dept. Agr., Off. Expt. Sta. Bul.* 34, 44 p. 1896.
62. SUCHTING, H. Über die schädigende Wirkung der Kalirphsalze auf die Kartoffel. *In Landw. Vers. Stat.*, 61: 397-449. 1905.
63. TAFT, L. R. Fertilizers upon potatoes. *Mich. Agr. Expt. Sta. Bul.* 131, p. 10, 11. 1896.
64. TAKEUCHI, T., and ITO, S. Note on the injurious effect of chloride. *In Bot. Mag.*, 25: 132, 133. 1911.
65. TOTTINGHAM, W. E. A quantitative chemical and physiological study of nutrient solutions for plant cultures. *In Physiol. Researches*, 1: 133-245. 1914.
66. TRELEASE, S. F. A study of salt proportions in a nutrient solution containing chloride, as related to the growth of young wheat plants. *Johns Hopkins Univ. Circ.*, p. 222-225. March, 1917.
67. VITUYNII, S. Amounts of chlorine and sulphuric acid in rain water. *In Chem. Abs.*, 6: 908. 1912.

68. VOELCKER, AUGUSTUS. Experiments with salt upon mangolds. *In Jour. Roy. Agr. Soc. England*, 25: 385-390. 1864.
69. ——. Field experiments on root crops. *In Jour. Roy. Agr. Soc. England*, 2d ser., 3: 500-530. 1867.
70. ——. Field experiments on clover seeds and permanent pasture. *In Jour. Roy. Agr. Soc. England*, 2d ser., 5: 73-97. 1869.
71. ——. Field experiments on potatoes. *In Jour. Roy. Agr. Soc. England*, 2d ser., 6: 392-415. 1870.
72. VOELCKER, J. AUGUSTUS. Salt experiments upon barley. *In Jour. Roy. Agr. Soc. England*, 3d ser., 2: 389. 1891.
73. ——. Woburn Experiment Station report on field and pot culture experiments, p. 21, 22. 1908.
74. WAGNER, P. Wassercultur Versuche mit Mais. *In Landw. Vers. Stat.*, 13: 218-222. 1871.
75. WHEELER, HOMER J. Manures and Fertilizers, xxi + 389 p. New York, 1913.
76. —, and HARTWELL, B. L. Conditions determining the poisonous action of chlorides. *In R. I. Agr. Expt. Sta. 15th Ann. Rpt. (1901-02)*, p. 287-304. 1902.
77. WOHLGEMUTH, J. Untersuchungen über Diastasen. I. Die tierischen Diastasen. *In Biochem. Ztschr.*, 9: 10-43. 1908.
Also the following, authorship not stated:
78. Methods of analysis of the Association of Official Agricultural Chemists. U. S. Dept. Agr., Bur. Chem. Bul. 107, rev., 272 p. 1908.
79. Hatch Expt. Sta. Mass. Agr. Coll. Bul. 18, 104 p. 1892. Also 7th Ann. Rpt., p. 119, 120, 185-194 (1895); 12th Ann. Rpt., p. 29-32 (1900); and 16th Ann. Rpt., p. 121, 122 (1904).
80. Experiments with fertilizers upon potatoes. *In N. J. Agr. Expt. Sta. Ann. Rpts.*, 11: 120-141, 1890; 12: 108-123, 1891.
81. Experiments with fertilizers upon turnips. *In N. J. Agr. Expt. Sta. 12th Ann. Rpt.*, p. 139-141. 1891.

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